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Some Flammability Characteristics of the Australian Army DPCU

Veronica Jeleniewski
and David Robinson

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Veronica Jeleniewski and David Robinson

Ship Structures and Materials Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

An examination of the flammability potential of several fabrics, commonly used by the Australian Army for the Disruptive Pattern Combat Uniform (DPCU), was undertaken. The materials examined were 50% cotton-50% polyester and 100% cotton. A 100% cotton treated with the flame retardant (FR) Proban® was also evaluated. It was found that various non flame retardant fabrics had similar potential hazards. Increases in weight were found to result in increased protection. The FR treatment was shown to provide flammability protection.

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Some Flammability Characteristics of the Australian Army DPCU

Executive Summary

As military personnel may be exposed to a wide range of thermal and fire threats, the clothing they wear must afford some level of resistance to ignition and combustion while still providing wearer comfort. At present the Australian Army has two types of combat uniforms. The in-service Disruptive Pattern Combat Uniform (DPCU) constructed using a 50% cotton-50% polyester blended yarn, this being light weight and durable, with the added advantage that the polyester component reduces the need for ironing and imparts ease of care. The second DPCU is manufactured using a 100% cotton flame retarded (FR) treated yarn and is mainly used by tank crew and Army aviators. Having differing types of combat uniforms has heightened the concern amongst military personnel that the in-service 50% cotton-50% polyester offers inferior flammability protection compared to that from the 100% FR cotton uniform.

With the exception of cotton jersey, all fabrics analysed were camouflage printed in the Australian pattern. Two different fabric weights were analysed for all fabric compositions, one was typical of the in-service shirt and the other, was typical of the in-service trouser. Two different print systems were analysed for the 50% cotton- 50% polyester blend fabrics: a vat-dispersed and a Basactiv system. Samples were tested singly and in combination with 100% cotton jersey material which is representative of material used in commercial undershirts.

The flammability characteristics of the fabrics were assessed by using such standard test methods as limiting oxygen index, time to ignition, flame spread and thermal protective performance.

Using these tests no significant differences were found to exist between the differing blend or print systems. As expected, different weights influenced the flammability performance, with the heavier weights and tighter weaves providing better protection. Similarly, the addition of a secondary fabric layer reduced the fabric flammability hazard. The addition of a flame retardant reduced the flammability of the 100% cotton DPCU. However, our results showed this protection was reduced when non FR treated cotton fabrics were used as undergarments and that the FR treated fabrics tested under a standard heat flux transmitted more heat. Although the intensity of the burn is likely to be more severe when wearing an FR treated fabric or FR fabric cotton jersey ensemble, it will be restricted to the area around the heat source. Both the non FR treated 100% cotton or the 50% cotton - 50% polyester fabrics continued to burn until extinguished by some external method. This produced a burn over a larger area. If melt stick, which is currently being addressed at these laboratories, is of no concern, then both the non FR treated 100% cotton, or 50% cotton - 50% polyester fabrics are considered suitable for general use.

Contents

1. Introduction

As military personnel may be exposed to a wide range of thermal and fire threats, the clothing they wear must afford some level of resistance to ignition and combustion while still providing wearer comfort. At present the Australian Army has two types of combat uniforms. The in-service Disruptive Pattern Combat Uniform (DPCU) constructed using a 50% cotton- 50% polyester blended yarn, this being light weight and durable, with the added advantage that the polyester component reduces the need for ironing and imparts ease of care. The second DPCU is manufactured using a 100% cotton flame retarded (FR) treated yarn and is mainly used by tank crew and Army aviators. Having differing types of combat uniforms has heightened the concern amongst military personnel that the in-service 50% cotton-50% polyester offers inferior flammability protection compared to that from the 100% FR cotton uniform.

The hazards caused by the combustion of flammable fabrics have existed as long as fabrics themselves. To reduce these hazards the process of combustion must be understood. In its simplest form combustion is seen as an interaction between heat, fuel and oxygen. This simple view is shown diagrammatically in Fig. 1.

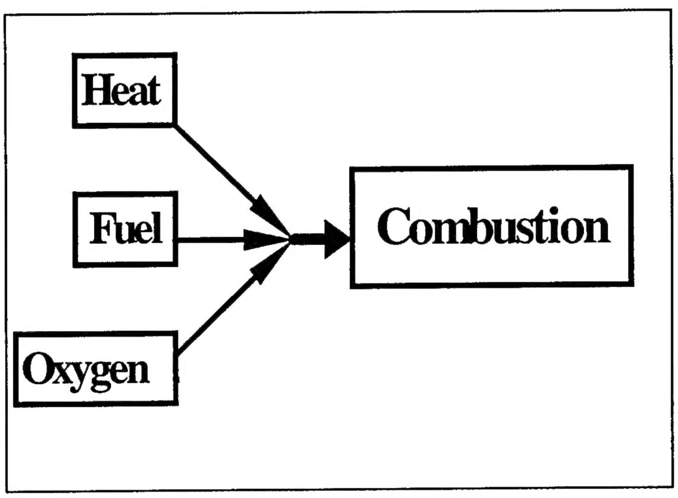

Figure 1: Simple Representation of Combustion

In reality, combustion is a complex phenomenon involving heating, decomposition, gaseous fuel generation, ignition and flame propagation. In sustained combustion these factors interrelate in a feedback mechanism as shown in Fig. 2.

For combustion to occur, the temperature of a substance must be raised to its decomposition temperature. The rate of this temperature rise is dependent on a number of properties including the specific heat of the material, the thermal conductivity, the latent heats of fusion and vaporisation as well as any other enthalpy changes which occur during heating. The decomposition or pyrolysis products generated are either flammable gases, non flammable gases, liquid condensates, tars or solid chars. In the presence of sufficient oxygen, the flammable gases that are the fuel source rapidly oxidise to produce heat and flame. Insufficient oxygen results in either the flame extinguishing or a slower rate of oxidation, such as smouldering. If excess heat is generated and transferred back to the material surface, more gaseous fuel due to thermal decomposition is produced and a self sustaining fuel cycle is created. This persists until the material is consumed or the cycle broken.

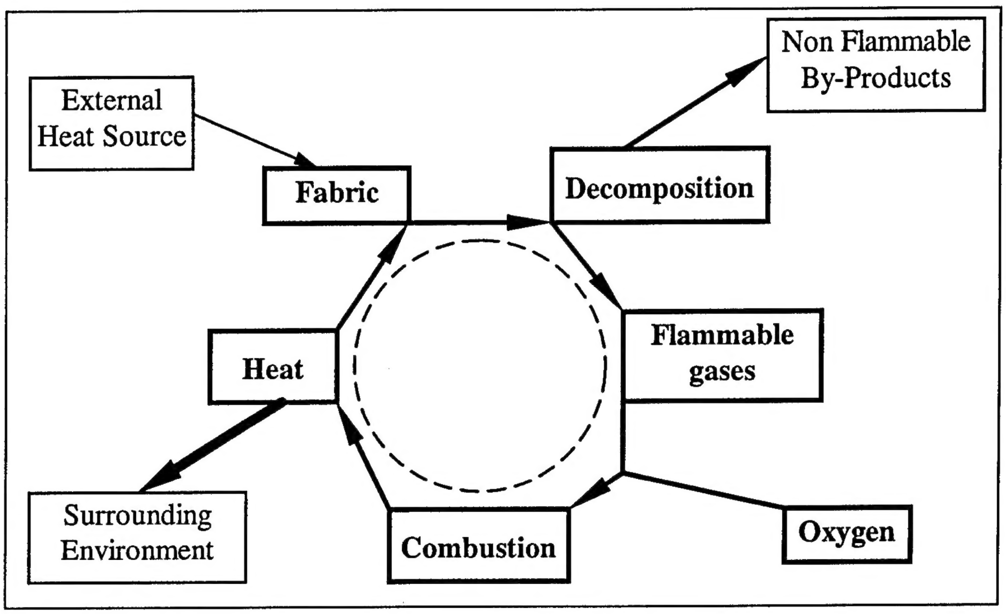

Figure 2: Feedback Mechanism of Combustion

Three types of products are emitted during the combustion process: smoke (which is a visible combination of gaseous, liquid and particulate substances), non visible gases and heat. These products are the most common hazards associated with a fire.

This report details the flammability resistance of fabrics manufactured from 50% cotton-50% polyester, 100% FR cotton and 100% cotton.

2. Experimental

Bench scale tests are most often used in laboratory studies on the flammability behaviour of textile materials. No single laboratory test can measure or simulate overall fabric flammability as the scale of laboratory experiments do not simulate actual fires. Laboratory results indicate the flammability potential of a material through the following tests:

(i) ignitability
(ii) rate of burning and
(iii) heat emission.

All fabrics were conditioned under standard laboratory conditions of 65 % RH and 21°C for a minimum of 24 hours prior to testing.

2.1 Ignitability

2.1.1 Limiting Oxygen Index (LOI)

This test is particularly useful for isolating the flammability effects of chemical composition from the variables of fabric construction. It provides a measure of the minimal volume fraction of oxygen in a slowly rising gaseous atmosphere, required to sustain candle-like burning. All LOI measurements were done using a Stanton Redcroft Flammability Test Apparatus. Tests were conducted in accordance with AS 2122.2 [i].

2.1.2 Ignition Time

The ignition time of a material is the time needed to cause sustained combustion when exposed to a known thermal source, whether flaming or non-flaming. The ignition time was determined according to AS 2755.1 [ii]. A propane flame was used as the ignition source for both ignition time and flame spread tests. For the non FR fabric, test specimen size was 80mm x 80mm while those with an applied FR treatment required a larger, 80mm x 200mm, test specimen.

2.2 Rate of Burning

2.2.1 Flame Spread

The rate of flame spread is a measure of the relative rate at which fabrics burn. This test involves holding a fabric in a fixed configuration, igniting and measuring the rate of linear combustion. Test configurations may be vertical, horizontal or any other desired angle. The orientation, test environment and available air supply will affect the rate of flame spread. Direct comparisons can only be made between samples tested under identical conditions. The vertical rate of flame spread was determined according to AS 2755.2 [iii]. A 5 second ignition time was recommended for fabrics with no FR treatment and a 15 second ignition time for FR treated fabrics.

2.3 Heat of Emission

2.3.1 Thermal Protection

The amount of thermal protection provided by a fabric is obtained from temperature and heat release measurements when subjected to either radiant, conductive or direct flame. The Thermal Protective Performance (TPP) rating is the product of heat flux seen by the fabric and exposure time. In these tests exposure time was the time required to cause a second degree burn. Tests were conducted according to ASTM D 4108 [iv]. All temperature measurements were made using calorimeters and computed against the time/tolerance data determined by Stoll et al [v]. The calorimeters were constructed from copper disks, with three thermocouples embedded, based on the design outlined in ASTM D 4108.

2.4 Materials

With the exception of cotton jersey, all fabrics analysed were camouflage printed in the Australian pattern. Two different fabric weights were analysed for all fabric compositions, one, the light weight, was typical of the in-service shirt and the other, the heavier weight, was typical of the in-service trouser. Two different print systems were analysed for the 50% cotton - 50% polyester blend fabrics: a vat-dispersed (V) and a Basactiv system (B). Table 1 lists the textile properties of all blends.

Table 1. Textile Properties of Fabrics Analysed.

Fabric Composition	Weave type	Mass g/m²	Thickness mm @ 6.9 N/m²
***100% Cotton Proban Treated**			
Shirting	2x1 Twill	211	1.17
Trousering	3x1 Twill	298	1.19
Shirting + Jersey		395	2.36
100 % Cotton			
Shirting	2x1 Twill	170	0.93
Trousering	3x1 Twill	252	1.08
Shirting + Jersey		354	2.20
50/50 Cotton/Polyester (V)			
Shirting	Oxford	178	0.93
Trousering	3x1 Twill	221	0.81
Shirting + Jersey		361	2.08
50/50 Cotton/Polyester (B)			
Shirting	Oxford	175	0.98
Trousering	3x1 Twill	219	1.27
Shirting + Jersey		359	2.08
Jersey			
100 % Cotton Jersey	Jersey Knit	184	1.29

* Proban® is a commercially available retardant based on tetrakis (hydroxymethyl) phosphonium chloride (THPC).

3. Results and Discussion

The flammability characteristics of the 50% cotton - 50% polyester in-service DPCU, a 100% cotton DPCU treated with Proban® FR and an untreated 100% cotton DPCU were analysed. Samples were tested singly and in combination with 100% cotton jersey material which is representative of material used in commercial undershirts.

3.1 Limiting Oxygen Index

The LOI for most materials is independent of the physical form and dimensions of the fabric. It is a measure of the varying chemical composition of the fibrous assembly and is routinely used to determine the effectiveness of a FR finish. It is generally accepted that materials with an LOI of greater than 26% are considered nonflammable.[vi] The LOI values for all samples tested are shown in Figure 3. The 100% cotton and 50% cotton 50% polyester, in both print systems, showed similar LOI's ranging between 16-17% which suggested that they would ignite and continue to burn in air, while the Proban® treated fabrics required approximately 27% oxygen before ignition occurred. These latter fabrics are therfore unlikely to ignite under normal atmospheric conditions where the concentration of oxygen is only 21 %. However, when used in combination

with the cotton jersey fabric as an undergarment the level of protection of the FR cotton fabric was reduced, the final value being 22.7%, which is an average of the LOI values of the individual fabrics. This reduction must be taken into consideration when personnel are wearing this type of undergarment with Proban® treated uniforms.

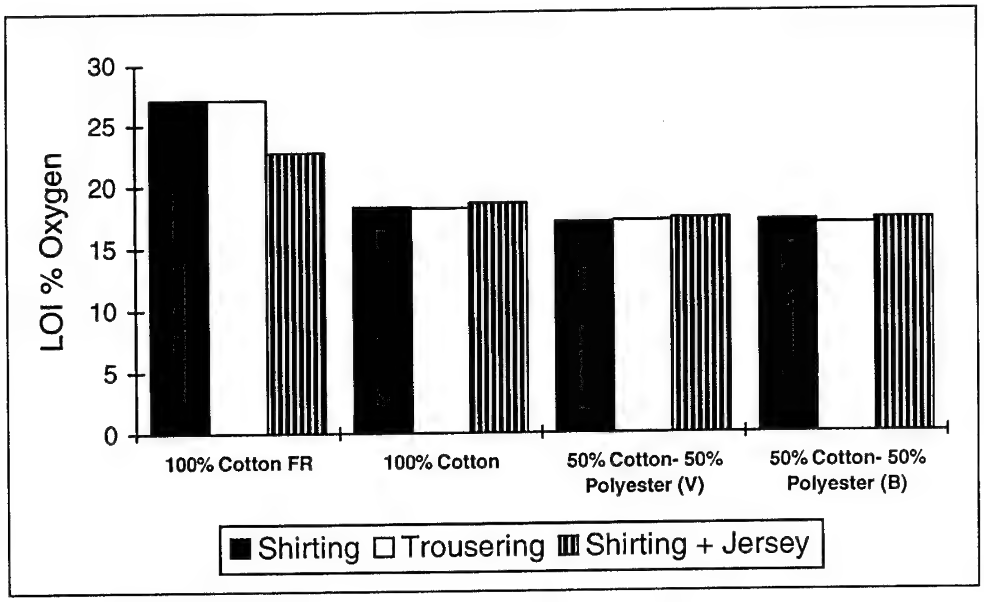

Figure 3 Limiting Oxygen Index

3.2 Time to Ignition

Ignition times were found to be similar for the 100% cotton and the 50% cotton-50% polyester materials at matching weights (Figure 4). As expected these times were increased when combined with the cotton jersey as an undergarment. These increases in ignition time were considered to result from the increase in weight due to the addition of the cotton jersey component of the ensemble. Although the Proban® treated shirting did not ignite when tested singly, ignition occurred when it was used in combination with the cotton jersey. This ignition was however short lived and the flame self extinguished after 10 - 12 seconds. These experiments clearly demonstrated that fabrics must not be considered in isolation and that the ignition properties are dependent on all fabrics in the ensemble. This is particularly important for Flame Retardant fabrics where the addition of any non flame retardant materials to the ensemble increases its likelihood of ignition when exposed to a naked flame. These results complement those from the LOI determinations.

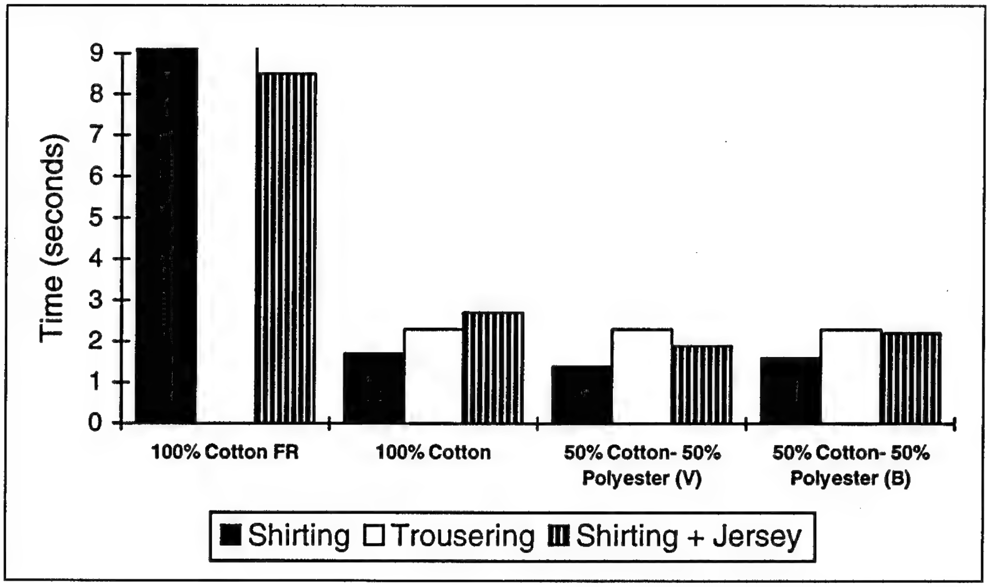

Figure 4: Time to Ignition.

3.3 Flame Spread

Figure 5 depicts the average vertical rate of flame spread per second. It was evident that the flame spread accelerated with time and that flame spread rates are mass dependent consequently the heavier a fabric or ensemble the slower it is consumed by flame. As the Proban® treated samples failed to ignite no flame spread occurred. It was also noted that although the Proban® treated shirting and cotton jersey ensemble was able to be ignited, the flame extinguished too quickly for a flame spread measurement could to be made.

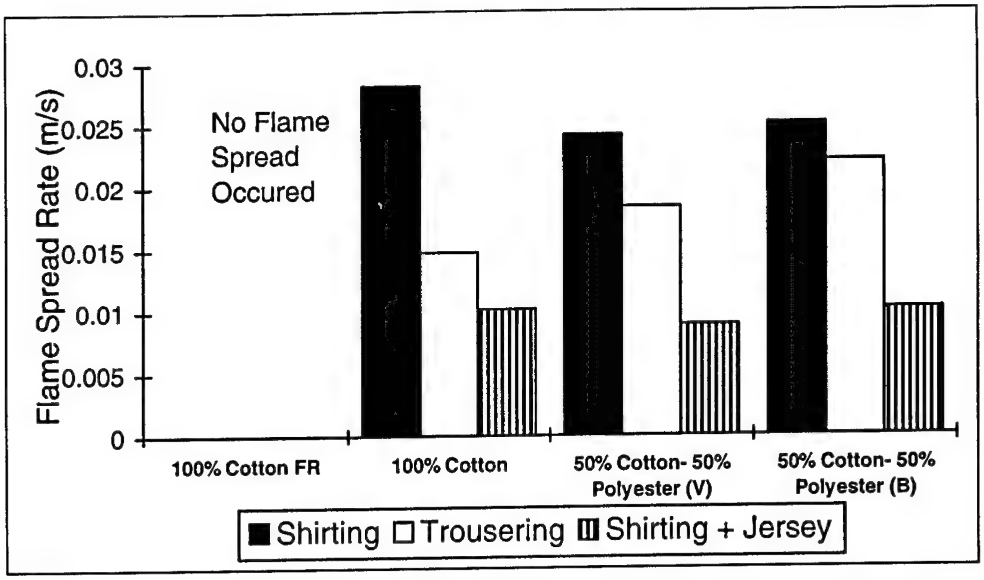

Figure 5: Rate of Flame Spread

3.4 Thermal Protective Performance

The Thermal Protective Performance (TPP) provides a basis for a qualitative ranking of fabrics under controlled test conditions. As shown in Figure 6, all fabrics except those treated with Proban® FR performed similarly. As expected, the inclusion of the cotton jersey as an undergarment improved the level of protection of the ensemble with the increase being almost directly proportional to the protective index (41.9 $kW.s/m^2$) of the cotton jersey. The Proban® treated samples suprisingly showed low TPP indices compared with either 100% cotton or 50% cotton-50% polyester. These low results are indicative of a greater amount of heat being transferred through the fabric. During evaluation of the Proban® FR treated fabrics some outgassing was observed and this resulted in a char being deposited on the calorimeters. It is considered that the lower TPP index is due to heat being transferred from the deposition products to the calorimeters. In practice this char would be deposited on the skin of the wearer. Similar results were obtained when the cotton jersey was used as an undergarment. In this instance the cotton jersey was consumed during testing leaving the calorimeter exposed to the Proban® treated fabric. The amount of heat transferred to the calorimeters during through the FR material or the FR material and the cotton jersey ensemble was greater than that for either the 100% cotton or the 50% cotton-50% polyester fabrics.

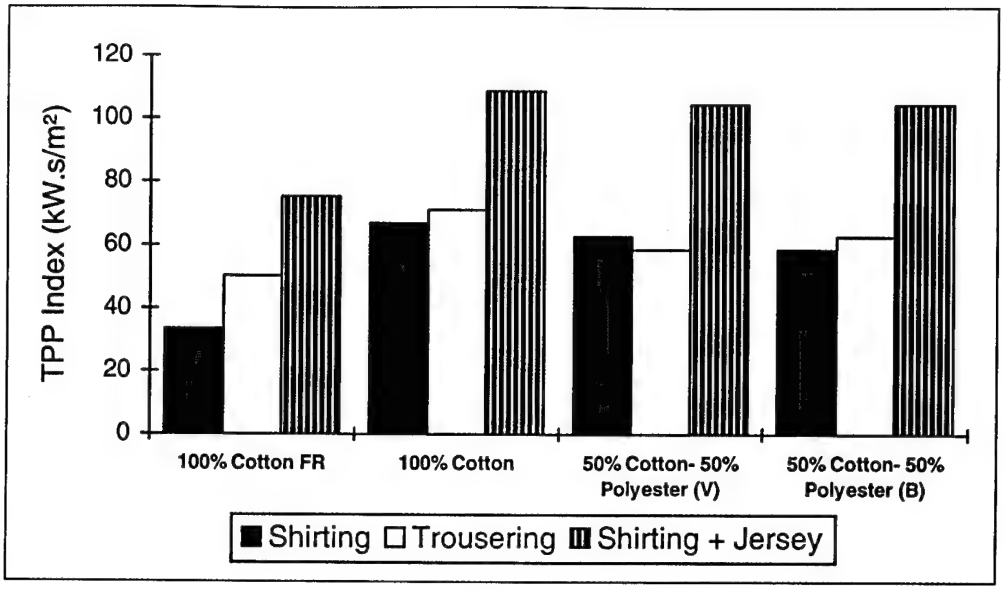

Figure 6: Thermal Protective Performance

4. Conclusion

The flammability assessments of non FR treated fabrics indicated that no significant differences existed between the differing blend or print systems. As expected, different weights influenced the flammability performance, with the heavier weights and tighter weaves providing better protection. Similarly, the addition of a secondary fabric layer can reduce the fabric flammability hazard. Proban® was shown to be effective in reducing the flammability of the 100% cotton DPCU. However, our results showed that this protection was reduced when non FR treated cotton fabrics were used as undergarments and that the Proban® treated fabrics, when tested under a standard heat flux of 8.3 kW/m^2, transmitted more heat. Although the intensity of the burn is likely to be more severe when wearing an FR treated fabric or FR fabric cotton jersey ensemble, it will be restricted to the area around the heat source. Both the non FR treated 100% cotton or the 50% cotton- 50% polyester fabrics continue to burn until extinguished by some external method. This will produce a burn over a larger area. If melt stick, which is currently being addressed at these laboratories, is of no concern, then both the non FR treated 100% cotton, or 50% cotton-50% polyester fabrics are considered suitable for general use.

5. References

i. AS 2122.2 Combustion Propagation Characteristics of Plastics Part 2 Determination of Minimum Oxygen Concentration for Flame Propagation, Standards Association of Australia.

ii. AS 2755.1 Determination of Ease of Ignition of Vertically Oriented Specimens, Standards Association of Australia.

iii. AS 2755.2 Measurement of Flame Spread Properties of Vertically Oriented Specimens, Standards Association of Australia.

iv. ASTM D 4108 Standard Test Method for Thermal Protective Performance of Materials for Clothing by Open Flame Method, American Society for Testing and Materials.

v. Stoll, A.M. and Chianta, M.A. Method and Rating System for Evaluation of Thermal Protection, Aerospace Medicine, Vol 40, 1968, pp 1232-1238.

vi. Tesoro, G.C. and Meiser, C.H. Jr. Some Effects of Chemical Composition on the Flammability Behavior of Textiles, Textile Research Journal, Vol 40, No. 5, 1970, pp 430-436.

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20. ABSTRACT

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